Support system development for forest ecosystem management

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Abstract

This paper discusses issues and requirements associated with the development of a spatial decision support system for the USDA Forest Service. A system was developed which integrates optimization based management planning models using map based representations of the spatial area being analyzed. This system was designed to address the decidedly hierarchical planning environment of the USDA Forest Service through the presentation of management alternatives in various forms, including impact visualization. This paper details some of the features of the developed spatial decision support system and demonstrates how optimization models are currently being made more informative through the presentation of results and further integrated within the planning structure of the USDA Forest Service. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

The USDA Forest Service has been forced to address a number of critical issues in their planning process. These changes have become necessary principally due to heightened concerns to protect habitat, the need for ensuring the survival of endangered species, the quest to promote bio-logical diversity, the provision of recreation, and the need for balancing these concerns with the ever present demand for timber. Among the critical requirements in the management of public lands are the following:

- Complex understanding of forest ecosystems.
- Consideration of public input.
- Sensitivity to the needs of industry.
- Methods to address risk and uncertainty.
- Information systems to map and inventory resources.
- Monitoring systems to track changes and regulation compliance.
- Techniques for evaluating policy changes.

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Many of these notions have been discussed by Loomis (1993) in great detail. Forest planning has evolved from a somewhat simple and straightforward management approach based on a multiple use concept to a complex, multi-faceted process involving a hierarchy of planning levels addressing large bioregions as well as relatively small stands. In order to adequately address complex problems, analysts and managers need appropriate information, good impact forecasting models, mechanisms to promote standards, and decision tools that aid in the development of land use plans.

Forest Service analysts have long relied on computer based modeling, especially linear programming, to address the complex problems involved in managing the 191 million acres of National Forest land (Kent et al., 1991). Perhaps the most well known forest modeling system is FORPLAN (Johnson et al., 1986). The use of FORPLAN was mandated for National Forest use since the passage of the National Forest Management Act of 1976 and continues to be an integral component of management plan development. Further, the use of FORPLAN has been considerable in the management planning of foreign and private forest lands as well. FORPLAN contains a variety of model forms specifically designed for forest resource planning. Such planning typically involves the allocation of forest land to management regimes for treatment and product output, which is developed through the incorporation of concerns for multiple use, ecosystem sustainability and protection of fragile environmental structures, among others (see Kent et al., 1991). These model forms are either linear programming (LP) or mixed integer-linear programming (MIP) problems. Commercially available software may be utilized for solving such models. In part, the flexibility in formulating and solving FORPLAN models has led to its reliance by USDA Forest Service planners for helping to identify and develop forest management plans.

Although FORPLAN provides valuable support in the generation of forest plans, a number of weaknesses do exist in the reliance of only FORPLAN in developing management alternatives (Bare and Field, 1987; Kent et al., 1991). One problem associated with the FORPLAN modeling approach is that high levels of spatial aggregation tend to be used, which leaves a great deal of uncertainty as to how to spatially distribute or disaggregate solutions (Church and Barber, 1992; Loh and Rykiel, 1992). This has led to the development of a spatial decision support system (SDSS) to assist analysts and decision makers in management plan generation called Regional Ecosystem and Land Management Decision Support System (RELMdss). This system is also designed to provide visual analysis of potential management alternatives and track interrelated activity between linked planning levels.

This paper presents details of a developed SDSS for the USDA Forest Service. A brief background is provided, which is followed by a discussion of the major system design issues. The linkages between spatial decision support systems and geographical information systems with regard to this particular planning environment are also examined. System details are provided through planning application use.

2. Background

The spatial detail typically represented in FORPLAN (and the more recent release, Spectrum) applied to an entire National Forest, as an example, is limited due to the considerable amount of aggregation associated with its design to be somewhat comprehensive (Barber, 1986; Bare and Field, 1987; Kent et al., 1991). Planners have typically faced the difficult task of translating activities in a large scale management plan to specific tracks of land. Such a process has generally been accomplished in some ad hoc fashion (Church and Barber, 1992). With specific harvesting goals on large tracks of land, management experts would plan stand treatment, road development, and schedule such activities over years or decades. As with many large scale planning efforts, the Forest Service planning process is decidedly hierarchical in nature (Church et al., 1994). Such a hierarchy represents the levels of analysis and decision making involved in an integrated forest planning study. The hierarchy typically ranges from large regions or bioregions with broad scale management goals down

to individual tracks of land allocated specific operational schemes as depicted in Fig. 1.

The top of the hierarchy involves large scale regional planning, like that represented as bioregions. The special report that addressed the spotted owl in the Pacific Northwest (Thomas et al., 1993) is an example of this level of planning. At the strategic level of the hierarchy is the planning of individual National Forests. Broad scale regional goals defined at the highest level are used to help guide management planning for each National Forest. This level of analysis has generally relied on the use of FORPLAN. Tracking numerous complex relationships and balancing a number of objectives, a FORPLAN model can be used to generate alternative management plans for a National Forest which are consistent with regional goals.

Given National Forest plans, each Ranger District is directed to manage their lands in concert with the strategic plan. Since the strategic plan was developed at a level of detail not representing specific tracks of land, but aggregated groups of strata and land, strategic plans must be translated to specific tracks of land at the tactical level. Since many simple translation techniques (like prorationing of FORPLAN solutions to smaller areal units) generally violate one or more of the standards and guidelines (represented as constraints) at the more spatially regulated planning level, this task has proven to be more complex than originally thought (Church et al., 1999). The constraints or standards and guidelines typically represent maximum treatment potential, sedimentation limits, species disturbance, etc. Tactical level planning has been accomplished in a number of ways. Spreadsheet and database programs have been used to try to assign activities to analysis areas in order to match as best as possible the overall targets identified by the FORPLAN model at the strategic level. Other approaches have included the use of FORPLAN (or Spectrum) and VIP-SDP (Church et al., 1992) as indicated in Fig. 1. Since a Ranger District is analyzed instead of the entire National Forest, it is possible to capture and model additional detail without the FORPLAN model becoming computationally too large.

The lowest level indicated in Fig. 1 is operational planning, where specific Project Areas are given prescriptions and timing decisions which include access, shipping, output levels, etc. subject to spatial restrictions imposed using adjacency constraints. Optimization models applied to this level of planning include SNAP II (Sessions and Sessions, 1993) and IRPM (Kirby et al., 1986).
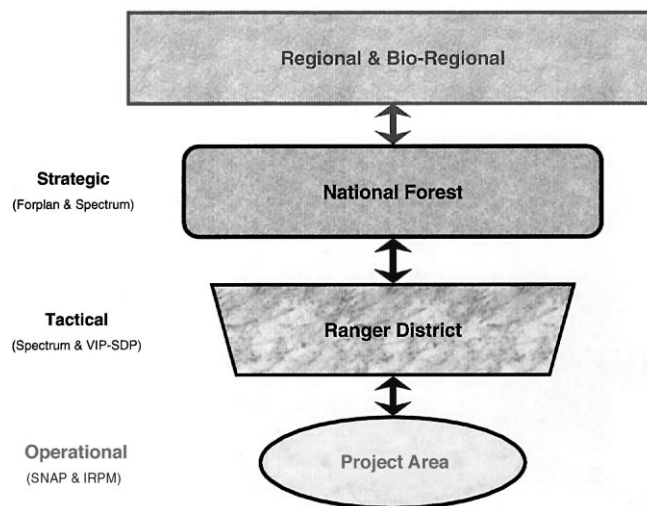

Fig. 1. USDA Forest Service planning hierarchy.

Each level of the hierarchy given in Fig. 1 has been addressed to some degree by the development and application of optimization models. A critical issue associated with the use of hierarchically based models to support forest planning is the need to integrate this process of modeling in a comprehensive manner that allows a user to estimate or account for activities on one level based on the set of goals/activities determined at other levels. As an example, an analyst should be able to analyze the impacts at a given level based on the analysis developed at another level (subject of course to the availability of sufficient data). Further, the process of hierarchical modeling should be accomplished within a reasonable period of time. Unfortunately, even less integrated approaches of analysis have often taken months or years to complete (Kent et al., 1991).

The hierarchical approach to forest management and decision making is very intuitive and conceptually appealing. It serves as a means for avoiding monolithic planning models that are not well understood and can be difficult to solve (Weintraub and Cholaky, 1991). More importantly, this hierarchy represents the planning environment of the USDA Forest Service, where output totals between the various planning levels are negotiated (Church et al., 1994). For these reasons, the hierarchical approach continues to be a critical component of the forest planning process (see for example, Hof and Baltic, 1991; Weintraub and Cholaky, 1991; Hof, 1993). No system or modeling tool has yet provided sufficient capabilities for supporting hierarchical decision making for USDA Forest Service management. It should be noted, however, there have been varied attempts to address the basic hierarchical approach to some degree (Covington et al., 1988; Davis and Martell, 1993). What is necessary is a decision support system which facilitates hierarchical analysis, presents information and results in a readily understandable form, provides a variety of display options including map based, somewhat open ended for future refinement, facilitates access to a geographical information system (GIS), integrates exterior models/programs, and operates in a real-time environment.

3. SDSS and GIS

Many of the needs of the Forest Service are well handled using a GIS. For example, inventory and management of detailed spatial data, system queries, and summary data display are readily accomplished using a GIS. However, the complexities associated with developing management plans have proven to be more than current GIS technology can address, and is perhaps outside the scope of what it should do. This has proven to be true for many spatial planning environments (Densham, 1991). For this reason, the need exists to develop modeling functionality outside of a GIS, but there is a desire to ensure that close ties to GIS exist (Loh and Rykiel, 1992). Thus, a SDSS is designed to address functionality and modeling issues rather than expressly managing the associated geographic data.

This represents an enigma in that much of what is provided in a GIS is still necessary and useful. However, the GIS working environment is not easily modified to accommodate many application specific details and considerations. Given the significant investment in GIS development and technology, it would not be wise to duplicate too much of this as it would detract from the original intent – something tailored to the planning problem at hand. The ultimate goal is a framework which integrates the capabilities of both GIS and SDSS.

Fig. 2 depicts the potential interaction of a SDSS and a GIS. The elected degree of integration of the two systems depends on the needs of the user and the purpose of the analysis. There are three designated pathways depicted in Fig. 2: (a) use of the GIS only (light arrows), (b) data input from the GIS into the SDSS for analysis with solution(s) being fed back to the GIS for further manipulation (gray arrows) and, (c) data input from the GIS into the SDSS for conducting analysis and making decisions (black arrows).

SDSS development has largely been viewed as a method represented by pathway (c) or a process which duplicates much of the functionality provided in a GIS. Recent developments in computer programming environments and software libraries are likely to facilitate a better linked process such as pathway (b).
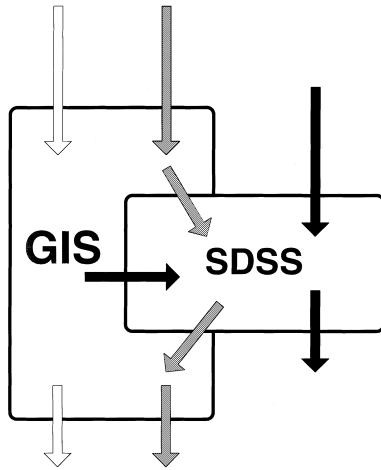
Fig. 2. Potential modeling pathways.

4. Development and application

The design of a SDSS for USDA Forest Service management planning had a number of application issues to consider. The development of RELMdss was based upon both user requirements and operational specifications.

First, the system was to be developed to operate on a personal computer under Windows. The design and representation of information display was to be based on providing an integrated hierarchical modeling framework capable of generating and analyzing potential management plans. Map based mediums were recognized as an important component of the plan generation process. The end product was to be a system that was easy to understand and use. Further, it was essential that the system facilitate the exploration and evaluation of alternative solutions. To this end, optimization based models were necessary in order to readjust scenario solutions in an efficient, equitable and relatively fast manner.

At the most basic level, functionality provided by RELMdss may be interpreted as the generation and visual display of different management schemes and alternatives. As standards and guidelines within areas are fairly well defined, an important feature of such displays are to indicate the extent to which spatial and temporal constraints are maintained, in addition to conveying

the achievement of scenario based goals and tracking forest attributes. In order to increase the visual representation of the forest landscape, RELMdss provides the capability for viewing graphics associated with actual or simulated forest areas in relation to potential treatment outcomes.

A RELMdss user screen is provided in Fig. 3 and depicts the Lassen National Forest using a proposed scenario treatment. The largest portion of the screen is devoted to the map. Each compartment is displayed as a polygon and is shaded with a color. The shaded color is defined in the legend given in the bottom right hand corner of the screen in Fig. 3. The color shading of RELMdss depicts the status level associated with each compartment. The status level represents a surplus, deficit or data inconsistency for each area or compartment based on the most constraining spatial restriction for that compartment. Various levels of red colors are used to depict increasing levels of constraint (standard or guideline) violation, while various levels of green are used to depict the levels of constraint surplus. The upper right section of Fig. 3 is a window that provides summary information, typically in tabular form, for a compartment or the region (constraint and output totals, attributes, etc.).

5. Land use structure

The basic spatial unit represented in RELMdss is a delineated compartmental unit (e.g., analysis area). The compartment can be further broken down into elements called components, however, they are not mapped. As stated previously, the spatial detail of a FORPLAN solution, as an example, is limited. When standards and guidelines are applied to compartments and components of a prorated FORPLAN solution, there can be (and often is) considerable violation. That is, there are constraints at the compartment and component level which have not been maintained. As an example, such constraints may represent a sedimentation limit in a watershed, a minimum level of open area in a habitat region, or maximum inventory in a planning unit. An additional spatial feature represented in RELMdss is the set, which
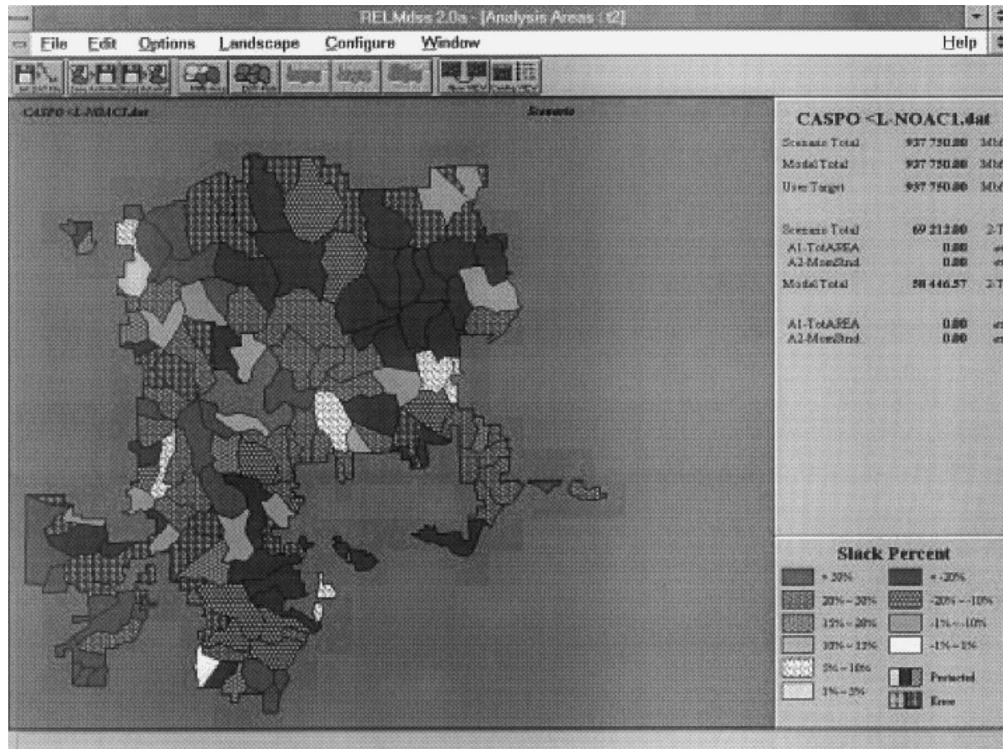
Fig. 3. RELMdss display of Lassen National Forest.

is a collection of compartmental areas. As with compartments and components, sets have unique constraints as well. The related structure of components, compartments and sets allows for a great deal of flexibility in representing and modeling land use problems. To further complicate things, areas must be sensitive to activities in other time periods. Thus, there is an explicit linkage between activity periods which impact spatial constraints.

6. Scenario solution analysis

There are a number of possible applications of the RELMdss system. One application has been to help translate a forest-wide plan (such as the one provided by FORPLAN) to more spatially detailed units. As an example, the higher level (or forest-wide) plan typically expects specific outputs from districts which contribute to the regional management plan. This can be volume output, habitat

creation or some other multiple use activity. The inherent difficulty arises because districts within a region have unique management requirements not necessarily represented explicitly in the higher level planning process. Fig. 3 depicts such an example, where the compartments have more detailed spatial constraints (standards and guidelines) compared to those originally imposed in the aggregate plan.

In order to view a scenario solution in RE-LMdss, a map of the compartment boundaries must be obtained from some digitized source (e.g., boundary file). To increase the ease of this process, a digitizing program called *DigitPlus* is also available (Church and Murray, 1993) which is both simple to use and produces the boundary files in the required format. Other options do exist, one being that no boundary file need be included, for which RELMdss simply generates square box representations of each compartment and/or set. It is worth pointing out that other topographical features such as rivers, roads, etc. may be necessary, but difficult

to obtain or generate. Thus, the above mentioned program is useful for this purpose as well.

The decision variables for the RELMdss planning model are defined for components and compartments. Given this, a proposed scenario solution attempting to attain forest-wide output goals or targets such as a prorated FORPLAN solution can be tested for feasibility against the compartment, component and set constraints being imposed throughout the planning horizon. That is, a forest-wide solution provides management targets for a more spatially defined level of planning.

As depicted in Fig. 3, the scenario solution for the Lassen National Forest is not particularly good. That is, in Fig. 3 there are instances where constraint violations occur in delineated watersheds as a result of maintaining specified target outputs or treatments. The area thresholds being imposed in this forest region include restrictions on the maximum amount of timber available within each watershed, limits on allowable eroded acres in the watersheds, and effective alteration constraints for watersheds. Since the scenario solution was generated at an aggregate level of detail (e.g., FORPLAN), it is likely that all spatial constraints that are applicable to the less aggregate level of analysis will not be met. For this reason, it is important to verify and potentially adjust scenario solutions to meet the required spatial restrictions that correspond to a more site specific level of analysis. As stated previously, this has proven to be a difficult task.

7. Maintaining spatial restrictions

Maintaining spatial constraints for the various planning levels was difficult if not impossible before RELMdss. Redistribution was done by either spreadsheet programs or other ad hoc methods. The modeling formulations provided in RELMdss allow for the redistribution of treatments through the use of linear programming models. These models are solved using C-WHIZ, a commercial software package, and is for all practical purposes transparent to the user, since nothing is necessarily required on the part of the user to solve the individual problem formulations. Any optimization package could be integrated for system use.

There are two basic optimization models that have been developed and included in RELMdss. The first model is called the Minimum Area model (MIN-Area). This model involves identifying activities that meet targets or goals as well as a general goal of minimizing the total acreage that is subject to treatment. For example, one might consider minimizing acreage needed for harvesting, subject to meeting harvesting goals and maintaining levels of oldgrowth acreage.

The following notation will be used to specify this model formulation:

i = index of compartments;

c = index of components;

j = index of thresholds or constraint types (e.g., area, regulation limits);

t = index of time periods;

o = index of concerns (e.g., volume, revenue, habitat);

l = index of sets;

s = index of subsets;

$\hat{j}$ = index of set thresholds;

w_{ct}^1 = weight given to acreage treated in component c in time period t;

w_{oct}^2 = weight given to concern o treatment of component c in time period t;

w_{ot}^3 = weight for violation of concern o target in time period t;

M_i = set of components in compartment i;

N_{ls} = set of compartments in subset s of set l;

$\beta_{i\,cot}$ = per acre contribution of component c in compartment i in time t to concern o;

δ_{icjtk} = coefficient to account for previous activity in time periods $k = 1, 2, \ldots, t$ in component c of compartment i in time t related to threshold j;

V_{ot} = target level for concern o in time period t;

T_{icjt} = threshold j of component c in compartment i at time period t;

$\hat{T}_{ijt}$ = threshold j of compartment i at time period t;

$\alpha_{ls\hat{j}tk}$ = coefficient to account for previous activity in time period $k = 1, 2, \ldots, t$ related to threshold $\hat{j}$ for subset s in set l at time period t;

$S_{ls\hat{j}t}$ = threshold $\hat{j}$ for subset s in set l at time period t.

Decision variables:

x_{ict} = component c acres treated in compartment i in time period t;

u_{ot} = target shortfall for concern o in time period t.

8. MIN-Area model

Minimize $$Z = \sum_i \sum_{c \in M_i} \sum_t w^1_{ct} x_{ict}$$
$$- \sum_o \sum_i \sum_{c \in M_i} \sum_t w^2_{oct} \beta_{i\,cot} x_{ict}$$
$$+ \sum_o \sum_t w^3_{ot} u_{ot}$$

subject to

(1) Concern target deviation is accounted for:

$$\sum_{k=1}^t \sum_i \sum_{c \in M_i} \beta_{i\,cot} x_{ict} + u_{ot} \geqslant V_{ot} \quad \forall o, t;$$

(2) Component and compartment treatment does not exceed thresholds:

$$\sum_{k=1}^t \delta_{icjtk} x_{ick} \leqslant T_{icjt} \quad \forall i, c \in M_i, j, t,$$

$$\sum_{c \in M_i} \sum_{k=1}^t \delta_{icjtk} x_{ick} \leqslant \hat{T}_{ijt} \quad \forall i, j, t;$$

(3) Treatment in sets does not exceed thresholds:

$$\sum_{k=1}^t \sum_{i \in N_{ls}} \sum_{c \in M_i} \alpha_{ls\hat{j}tk} x_{ick} \leqslant S_{ls\hat{j}t} \quad \forall l, s, \hat{j}, t;$$

(4) Define decision variables:

$$x_{ict}, u_{ot} \geqslant 0 \quad \forall i, c \in M_i, o, t.$$

The objective of the MIN-Area model is to minimize the weighted total area treated, to maximize the total weighted concern treatment, and to minimize the under achievement of reaching concern goals. The objective weights, w, are typically adjusted to reflect the relative importance of the various functional elements. An arbitrary set of initial values is to set the weights equal to one. This is the default setting of RELMdss. It should be noted that in RELMdss a non-declining yield op-

tion is included, however, this portion of the formulation has been omitted for clarity.

The second basic model provided in RELMdss is the Equivalent Risk model (EQV-Risk) which attempts to spread activities across the planning area whenever flexibility in constraints permits. EQV-Risk attempts to distribute treatment activity among areas as it pertains to the strictest constraint faced in each unit. That is, the model must determine a solution that optimizes one or more objective terms as well as minimize the largest percentage of any threshold constraint reached by the assignment of activity.

Additional notation for the EQV-Risk model formulation is the following:

$\hat{w}$ = weight associated with percentage deviation from thresholds.

Decision variable:

D = maximum percentage of threshold that is treated.

9. EQV-Risk model

Minimize $$Z = \hat{w} D + \sum_o \sum_t w^3_{ot} u_{ot}$$

Subject to

(5) Concern target deviation is accounted for:

$$\sum_{k=1}^t \sum_i \sum_{c \in M_i} \beta_{i\,cot} x_{ict} + u_{ot} \geqslant V_{ot} \quad \forall o, t;$$

(6) Component and compartment treatment does not exceed percentage of thresholds:

$$\sum_{k=1}^t \delta_{icjtk} x_{ick} \leqslant T_{icjt} D \quad \forall i, c \in M_i, j, t,$$

$$\sum_{c \in M_i} \sum_{k=1}^t \delta_{icjtk} x_{ick} \leqslant \hat{T}_{ijt} D \quad \forall i, j, t;$$

(7) Component and compartment treatment must not exceed first threshold:

$$\sum_{k=1}^t \delta_{ic1tk} x_{ick} \leqslant T_{ic1t} \quad \forall i, c \in M_i, t,$$

$$\sum_{c \in M_i} \sum_{k=1}^{t} \delta_{ic1tk} x_{ick} \leqslant \hat{T}_{i1t} \quad \forall i, t;$$

(8) Treatment in sets does not exceed thresholds:

$$\sum_{k=1}^{t} \sum_{i \in N_{ls}} \sum_{c \in M_i} \alpha_{ls\hat{j}tk} x_{ick} \leqslant S_{ls\hat{j}t} D \quad \forall l, s, \hat{j}, t;$$

(9) Define decision variables:

$$x_{ict}, u_{ot}, D \geqslant 0 \quad \forall i, c \in M_i, o, t.$$

The objective of the EQV-Risk model is to minimize the weighted percentage of thresholds reached and to minimize the under achievement of reaching concern goals. Again, a non-declining yield option is available, but omitted for clarity.

Applying the MIN-Area model to the Lassen National Forest shown in Fig. 3, results in the redistribution of activities displayed in Fig. 4. Notice that all violations have been eliminated

and the targeted output total has been achieved (summarized in the information window of Fig. 4 – Model and Scenario Total). Specifically, the Scenario and Model totals are the same in Fig. 4 for the second time period, which indicates that the MIN-Area model was able to achieve the Scenario output levels but did so without violating standards and guidelines. In particular, the violations associated with the watershed allowable eroded acres thresholds and area control constraints depicted in Fig. 3 are now maintained in the management alternative shown in Fig. 4. This is the case for all four time periods. Although it was not done for this example, an important feature of RELMdss is its ability to allow for user interaction through the modification of weights associated with the various objective function considerations specified, then re-running the model. This is accomplished through the use of a dialog box, where default weight values may be easily adjusted and the model(s) re-run. In addi-
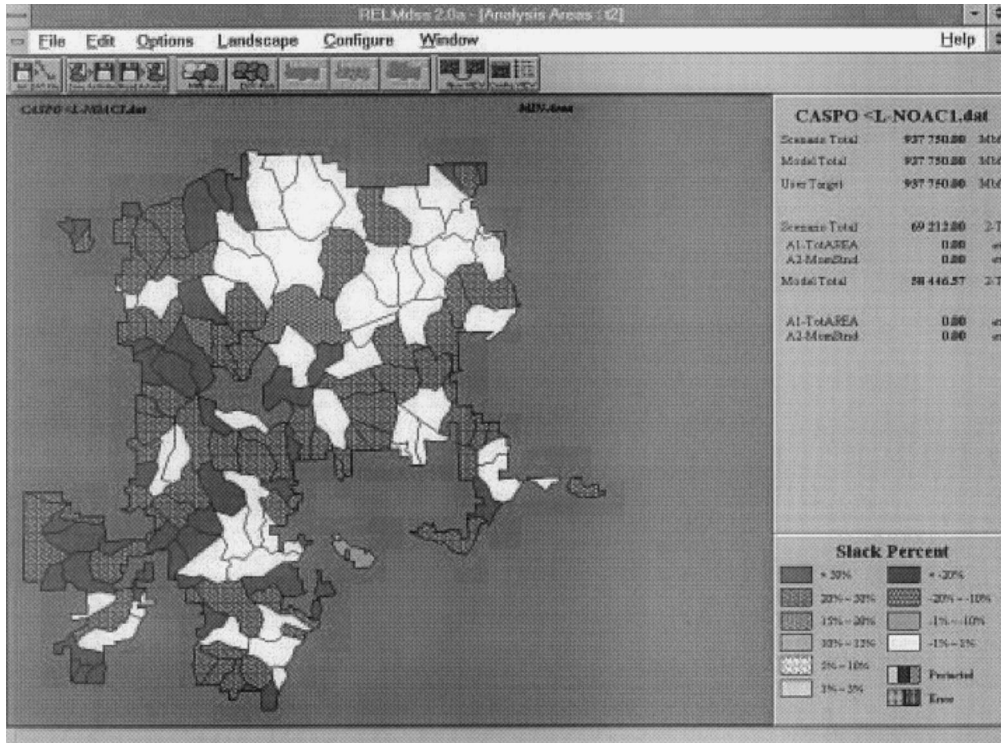

Fig. 4. MIN-Area RELMdss display of Lassen National Forest.

tion, the user can interactively specify activities in certain areas (set in, block out or adjust compartment activity) then the model may be re-run. Basically, the initial run of a MIN-Area or EQV-Risk model is a beginning point from which an analyst works toward an acceptable management plan facilitated by the use of RELMdss. This modeling environment enables potential alternatives to be visually displayed and quickly examined, thereby reducing response time. Given this, results from both the MIN-Area and EQV-Risk models are evaluated to determine which is more suitable for the particular planning application. This is driven by forest management objectives, industry commitments, public desires, etc.

This system represents a planning environment for which mathematical modeling has the opportunity to both provide insights and suggest alternatives as discussed in Geoffrion (1976). This is an important contribution of SDSS in that meaning

and spatial interpretation is attached to results, making them more readily understandable. Further, the interactive capabilities facilitate the generation of management alternatives and solution/plan adjustments.

10. Additional modeling issues

In addition to the RELMdss capabilities for interactively developing management plans through the use of the MIN-Area and EQV-Risk models, planning alternatives generated using external programs may be easily imported and analyzed in RELMdss. In fact, this was done for operational problems analyzed in Murray and Church (1995).

Carrying out hierarchical analysis using RELMdss has not yet been demonstrated. Fig. 5 shows the Lassen National Forest and the Sierra Nevada forests, which are apart of the California
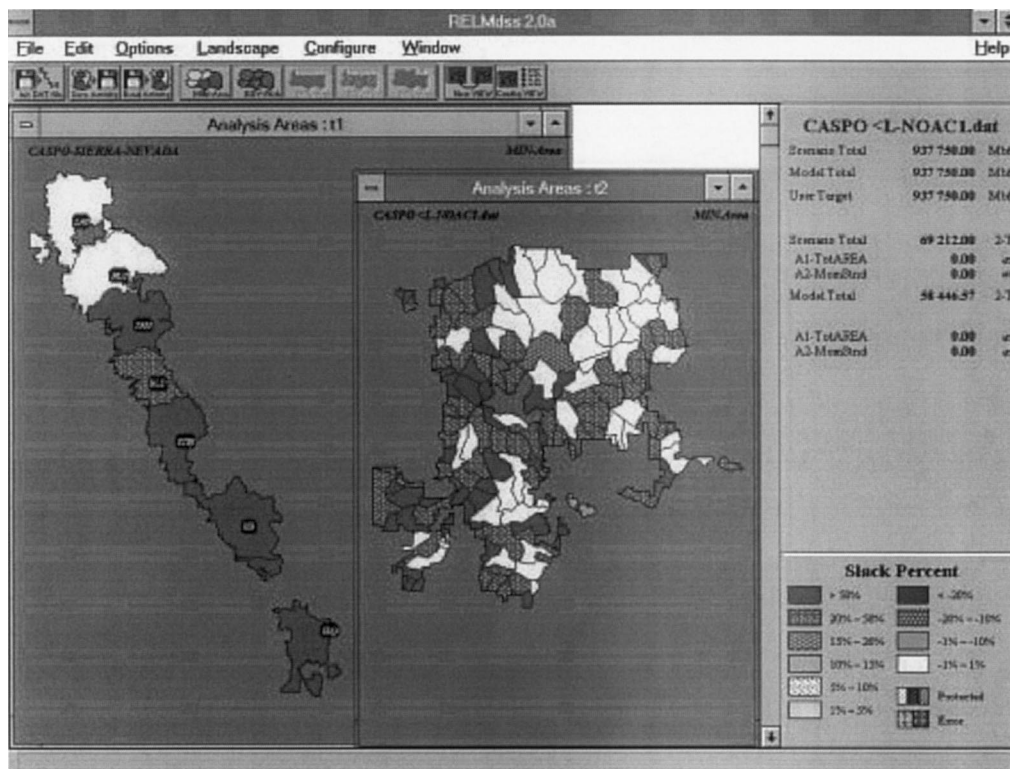

Fig. 5. Hierarchical RELMdss display.

Spotted Owl study area. The Lassen National Forest is actually a planning unit within the Sierra Nevada study area. The Lassen National Forest represents a lower level in the planning hierarchy and the spatial detail is increased in terms of the standards and guidelines being imposed. Thus, the management planning of these two levels is linked. Such linkages are established in RELMdss through dialog boxes accessed from menu pull downs. When planning models are solved at either level, the activity totals are integrated in the other level(s). As an example, the model output totals in Fig. 5 for each period are relayed to the higher level, which for the second period is 937,750 MBF in this case. This process allows for negotiation to take place when differences or inconsistencies arise between decision hierarchies. Given the above modeling capabilities, the potential for developing integrated and coordinated plans is enormous. For further details and discussion of the hierarchical capabilities of RELMdss, the interested reader is referred to Church et al. (1994).

RELMdss is continuing to be extended and refined in order to better address problems faced by Forest Service personnel. One of the newest modeling extensions includes modifying the MIN-Area and EQV-Risk models in order to produce desired future conditions. That is, the goal is to move certain output or activities into a desired state at the end of the planning horizon. It is expected that similar extensions and additions will be integrated and developed as the needs of Forest Service personnel evolve.

11. Conclusions

Recognizing the need to support hierarchical analysis within one system, the USDA Forest Service has supported the development of a modeling and visualization system. This spatial decision support system (SDSS) is designed to integrate data and outputs from various levels, manage models across levels of analysis, display results using maps and visualization scenes, be somewhat linked to a geographical information system (GIS), and provide an analyst with the capability to perform timely and comprehensive analyses. The system is called RELMdss and operates on a personal computer. RELMdss is currently being used throughout the USDA Forest Service and allows a user to represent and view the analysis of land resource planning. RELMdss provides a linkage for representing hierarchical relationships, supports temporal analysis, and can be used to analyze problems at different scales.

RELMdss is based on two principal management models which assist in the disaggregation of less geographically specific forest plans. The interface allows a user to analyze multiple forests at the same time as well as simultaneously view plans in different time periods. The models can support analysis which reflect the tactical level, as supported in the VIP-SDP system (Church et al., 1999), as well as some forms of FORPLAN at the strategic planning level. The major features of RELMdss are that it allows for significant interaction on the part of the analyst and presents solutions in a topographical interface that facilitates planning alternative understanding. The development and use of RELMdss in USDA Forest Service planning has helped change and improve land use management.

Acknowledgements

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